QoE Assessment of Object Softness in Remote Robot System with Haptics

~ Comparison of Stabilization Control ~

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Outline

1. Background
2. Purpose
3. Remote Robot System with Haptics
4. Stabilization Control (four types)
5. Assessment Method
6. Assessment Results
7. Conclusion and Future Work

Background

- Remote robot systems with haptics have been actively researched.
- It is possible to transmit the information about the shape, weight, and softness of a remote object by using haptic interface devices.

The efficiency and accuracy of work can largely be improved.

Transmission of haptic sense over the Internet

QoE (Quality of Experience) degradation and instability phenomena in remote robot systems with haptics owing to the network delay, delay jitter and packet loss.

- ◆ Stabilization control
- ◆ QoS (Quality of Service) control

Previous Work (1/3)

*1 K. Suzuki *et al.*, Proc. IEEE GCCE, Oct. 2015.
*2 P. Huang *et al.*, IEICE, CQ2016-125, Mar. 2017.
*3 P. Huang *et al.*, IEICE, CQ2017-79, Nov. 2017.
*4 T. Rikiishi *et al.*, IEICE Society Conference, BS-7-21, Sep. 2017.

- For stabilization, the **stabilization control with filters** *1 was applied to a remote robot system with haptics *2.

→ There is a problem of vibration against hard objects.

- An improvement method *3 was studied to improve haptic quality in the stabilization control with filters.

→ It is effective for hard objects, but the effect is small for soft objects.

- To suppress instability phenomena, the **stabilization control by viscosity** *4 was proposed.

→ The robot arm jumps up when the arm hits hard objects.

Previous Work (2/3)

*5 R. Arima *et al*., IEICE, CQ2017-98, Jan. 2018.
*6 Q. Qian *et al*., IEICE Global Conference, BS-2-14, Mar. 2018.

- To prevent the robot arm from jumping up when the arm hits a hard object, the **reaction force control upon hitting** *5 was proposed.

→ In a preliminary experiment, the stabilization control by viscosity is effective for soft objects, and the reaction force control upon hitting is effective for hard objects,

- For combining the advantages of the stabilization control by viscosity and the reaction force control upon hitting, the **switching control** *6 was proposed for the remote robot system with haptics.

→ The **switching control** uses the **stabilization control by viscosity** for soft objects and the **reaction force control upon hitting** for hard objects.

*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.

Previous Work (3/3)

The four types of stabilization control have their own features.

→ **Comparison** →

Clarify the applicability of each control to use them effectively.

However, only comparison between the **reaction force control upon hitting** and the **stabilization control with filters** was carried out [*5].

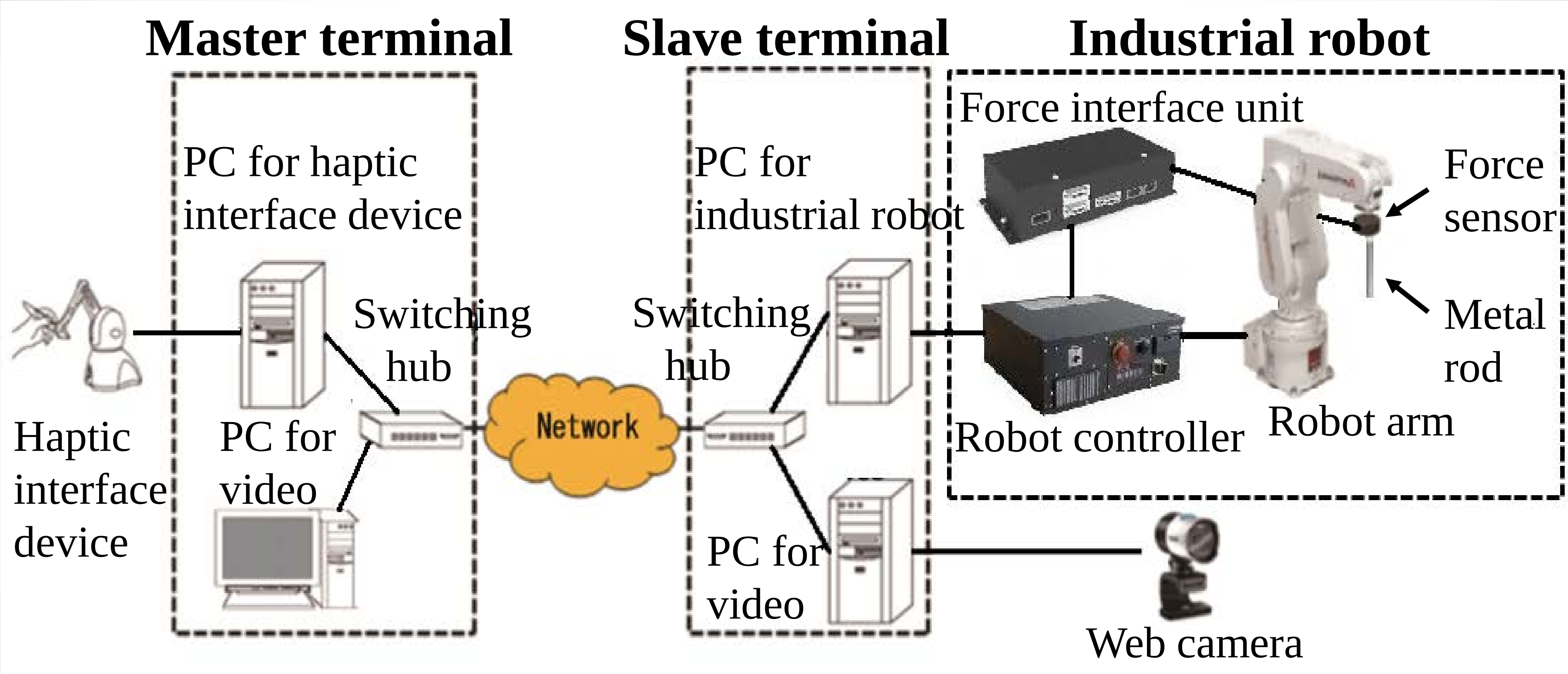
Purpose

This work

- We deal with the four types of stabilization control for the remote robot system with haptics.

- We compare their effects by carrying out QoE assessments for the other combinations of the control excluding the following combinations:
  - ✓ *The **switching control** and the **stabilization control by viscosity***
  - ✓ *The **switching control** and the **reaction force control upon hitting***

Remote Robot System with Haptics

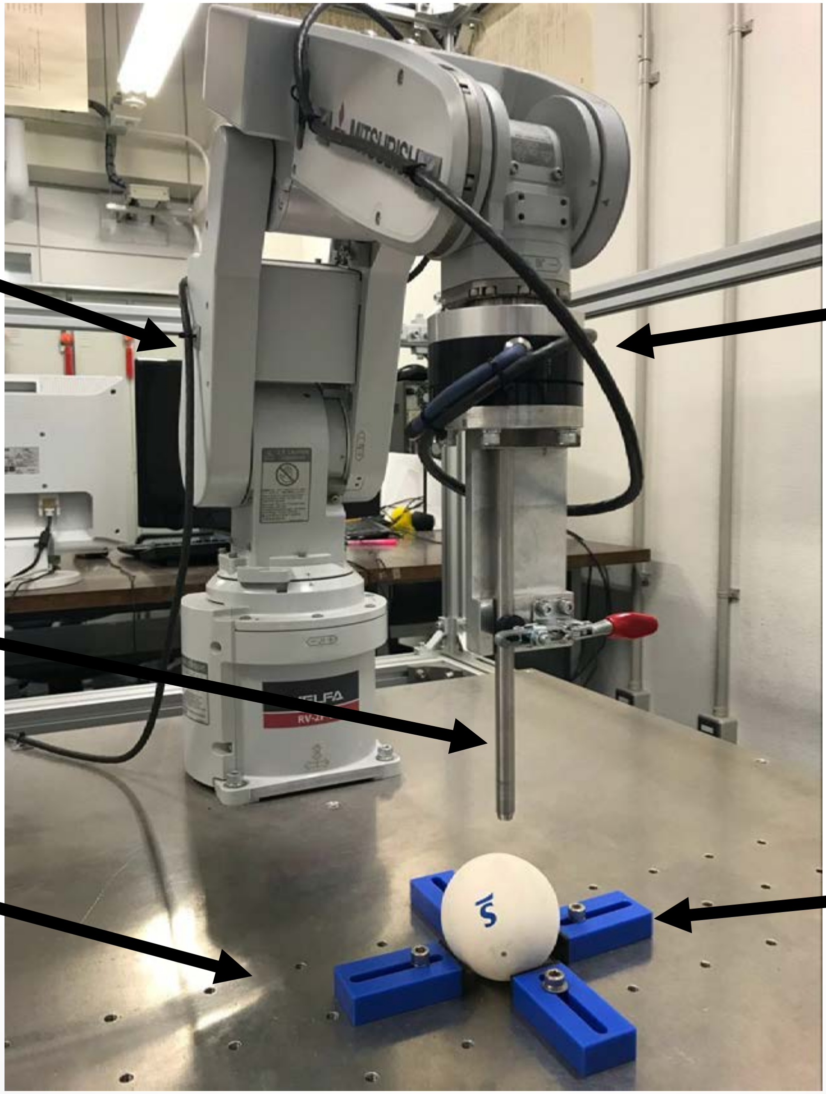


Industrial Robot Arm

Industrial robot arm

Force sensor

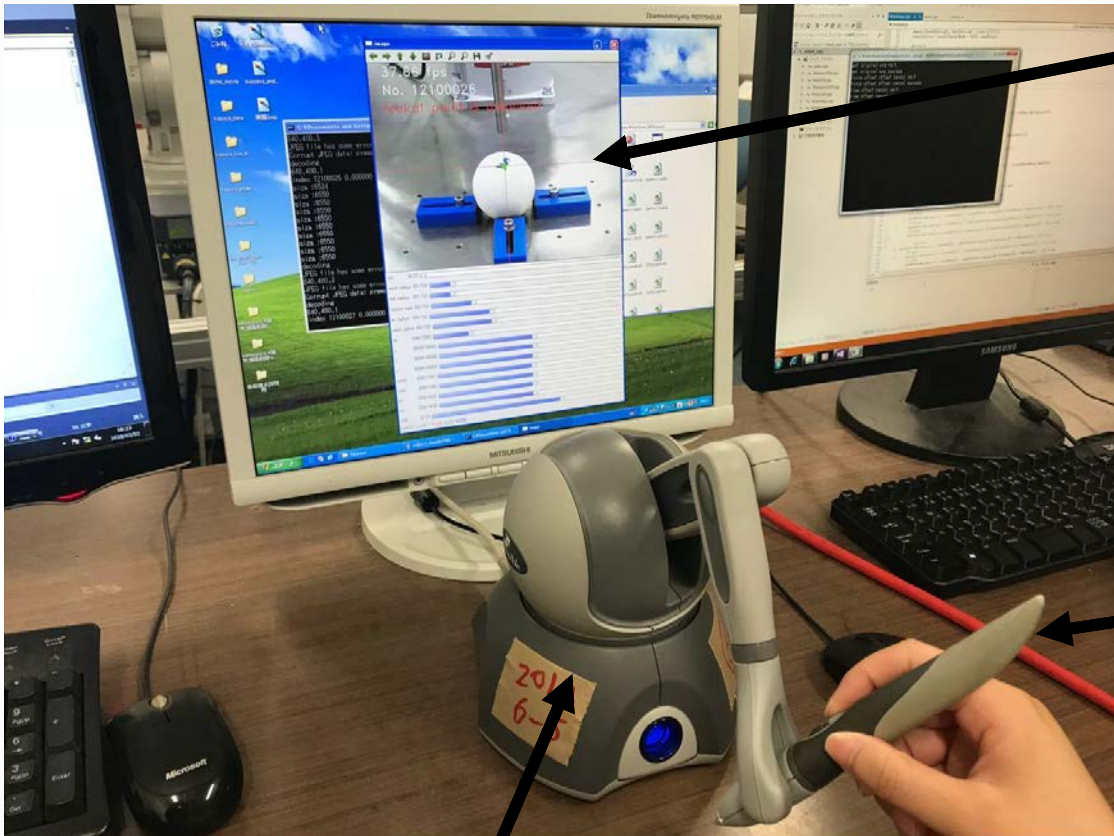
Metal rod



Metal platform

Holding jigs

Haptic Interface Device



Video

Stylus

Geomagic Touch

Calculation for Reaction Force

$$\boldsymbol{F}_t^{(\mathrm{m})} = \begin{cases} K_{\mathrm{scale}} \boldsymbol{F}_{t-1}^{(\mathrm{s})} & (K_{\mathrm{scale}} |\boldsymbol{F}_{t-1}^{(s)}| < 3.3 \text{ N}) \\ 3.3 \dfrac{\boldsymbol{F}_{t-1}^{(\mathrm{s})}}{|\boldsymbol{F}_{t-1}^{(\mathrm{s})}|} & (\text{otherwise}) \end{cases}$$

(Maximum allowable reaction force)

$\boldsymbol{F}_t^{(\mathrm{m})}$: Reaction force outputted at time t (≥ 1)

$\boldsymbol{F}_t^{(\mathrm{s})}$: Force received from slave terminal at time t (≥ 1)

K_{scale} : Mapping ratio about scale of force

Force (Robot : Geomagic)
1 : 1 (1)

K_{scale}

Robot: Industrial robot arm

Geomagic: Haptic interface device

*3 P. Huang *et al.*, IEICE, CQ2017-79, Nov. 2017.

Calculation for Position of Industrial Robot Arm

$$\boldsymbol{S}_t = 0.5\boldsymbol{M}_{t-1}$$

$\boldsymbol{S}_t$: Position vector of industrial robot arm at time t (≥ 1)

$\boldsymbol{M}_t$: Position vector of haptic interface device at time t (≥ 1)

Work space (Robot : Geomagic)
1 : 2 (0.5)

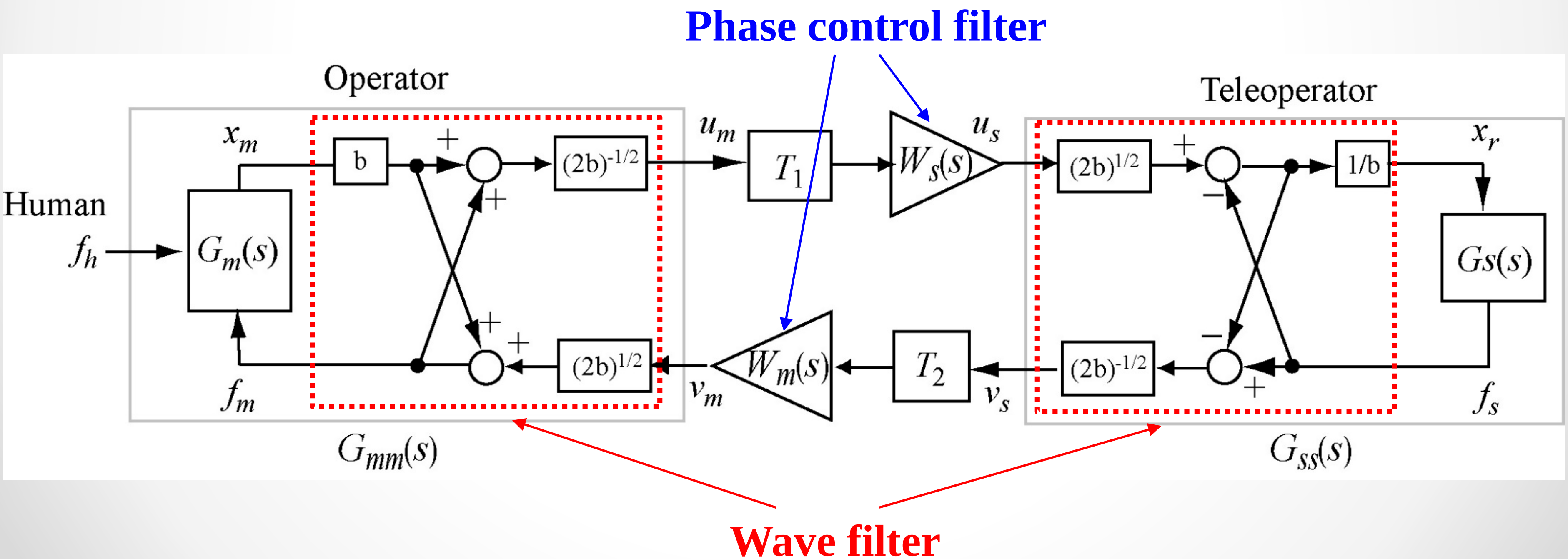
Robot: Industrial robot arm
Geomagic: Haptic interface device

Mapping ratio about scale of work space [*3]

*3 P. Huang *et al*., IEICE, CQ2017-79, Nov. 2017.
*7 T. Miyoshi *et al*., Proc. IEEE CCA, pp. 1318-1324, Oct. 2006.
*8 M. D. Duong *et al*., Proc. 17th IFAC World Congress, pp. 12715-12720, July 2008.

Stabilization Control with Filters

- The stabilization control with filters uses the wave filter in combination with the phase control filter [*7, *8].
- The control can make the remote robot system with haptics stable against any network delay [*3].



*4 T. Rikiishi *et al.*, IEICE Society Conference, BS-7-21, Sep. 2017.

Stabilization Control by Viscosity

$$\boldsymbol{S}_t = 0.5\boldsymbol{M}_{t-1} - C_{\mathrm{d}}(0.5\boldsymbol{M}_{t-1} - \boldsymbol{S}_{t-1})$$

C_{d} (=0.95 [*4]) : Coefficient related to viscosity

$\boldsymbol{S}_t$: Position vector of industrial robot arm at time t (≥ 1)

$\boldsymbol{M}_t$: Position vector of haptic interface device at time t (≥ 1)

*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.

Reaction Force Control upon Hitting

$$\boldsymbol{F}_t^{(\mathrm{m})} = \begin{cases} K_{\mathrm{scale}}\left(\boldsymbol{F}_{t-1}^{(\mathrm{m})} + K_i \boldsymbol{F}_{\mathrm{th}}\right) & \left(\left|\boldsymbol{F}_{t-1}^{(\mathrm{m})} - K_{\mathrm{scale}} \boldsymbol{F}_{t-1}^{(s)}\right| > \left|\boldsymbol{F}_{\mathrm{th}}\right|\right) \\ K_{\mathrm{scale}} \boldsymbol{F}_{t-1}^{(\mathrm{s})} & (\text{otherwise}) \end{cases}$$

$\boldsymbol{F}_t^{(\mathrm{m})}$: Reaction force outputted at time t (≥ 1)

$\boldsymbol{F}_t^{(\mathrm{s})}$: Force received from slave terminal at time t (≥ 1)

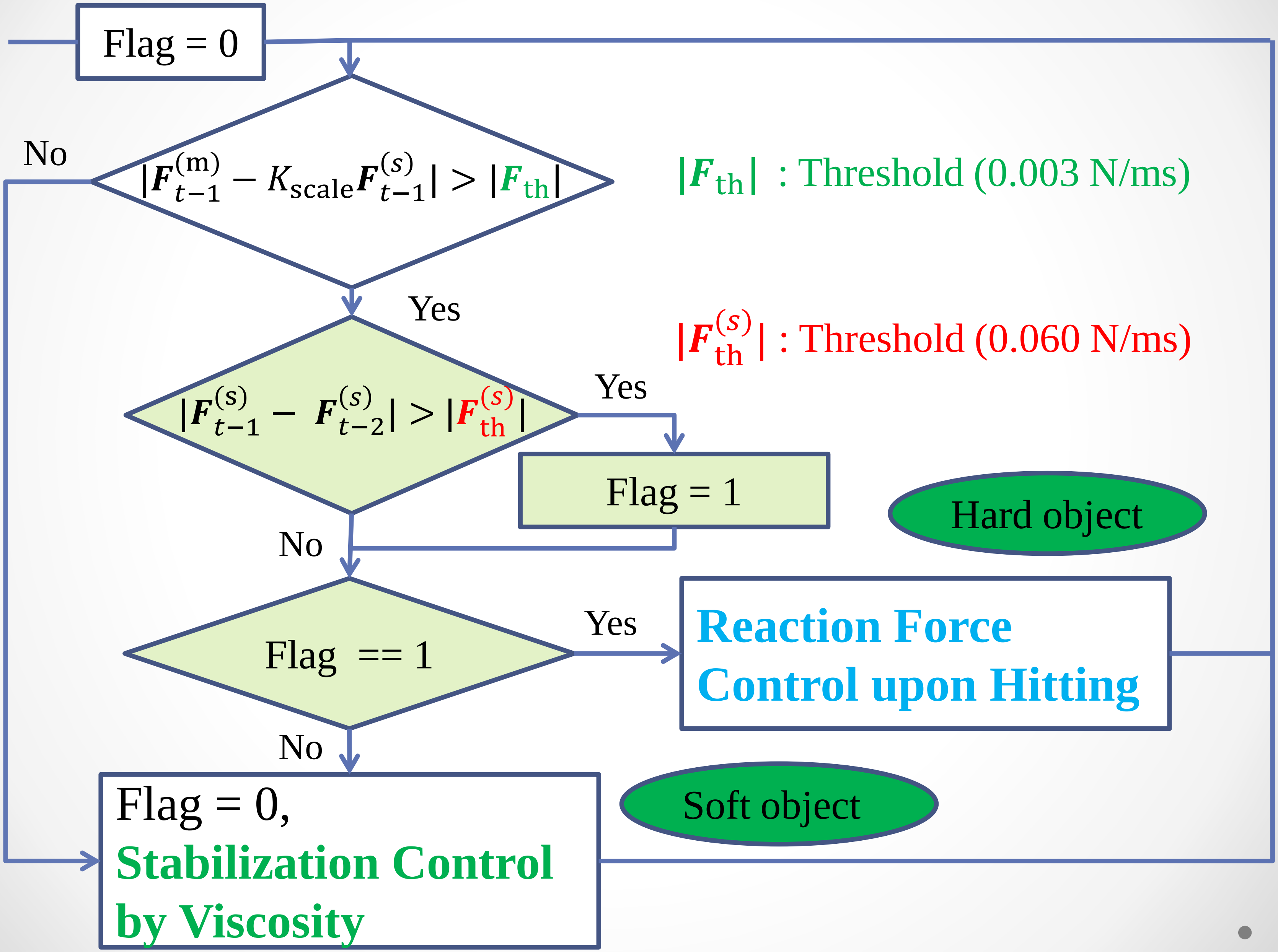
K_{scale} : Mapping ratio about scale of force

$|\boldsymbol{F}_{\mathrm{th}}|$: Threshold (0.003 N/ms),

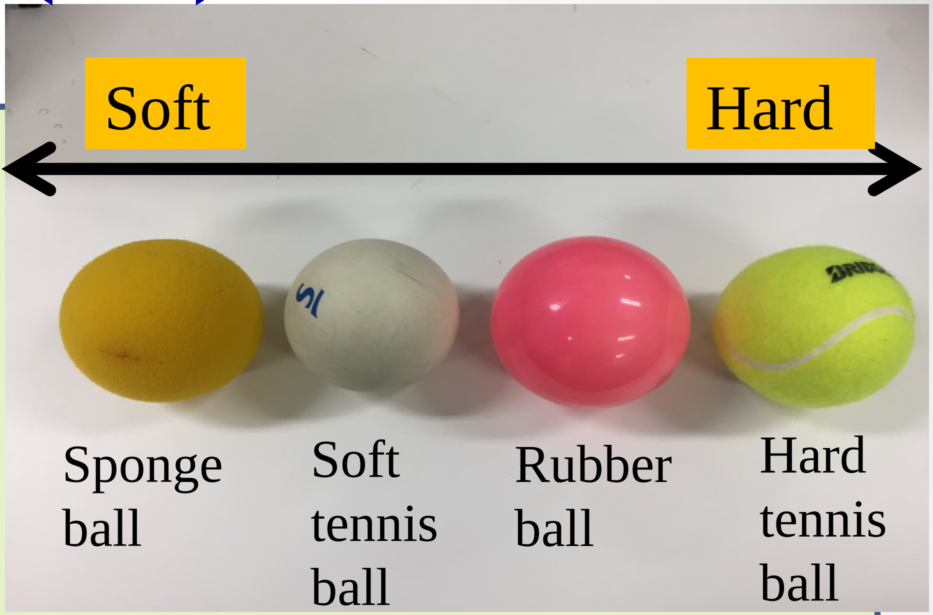
K_i : Increment rate of force

$K_i = 1.000 + 0.001i \quad (i \geq 0)$ *5

Switching Control



Assessment Method (1/3)



- Each subject did work of pushing four balls with different softness by a metal rod attached to the tip of the industrial robot arm.
- The industrial robot arm was set to move only in the vertical direction.
- The subject pushed each ball five times for about 10 seconds.
- There were 15 subjects whose ages were between 24 and 30.

*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.

Assessment Method (2/3)

- Three assessments of object softness:

1. Assessment between the **stabilization control by viscosity** and the **stabilization control with filters**
2. Assessment between the **switching control** and the **stabilization control with filters**
3. Assessment between the **stabilization control by viscosity** and the **reaction force control upon hitting**

Assessment between the **reaction force control upon hitting** and the **stabilization control with filters** has already been done [*5].

Assessment Method (3/3)

- Each subject answered which control between the two types of control produced the closer feeling of pushing the ball with hand via the stylus of the haptic interface device.

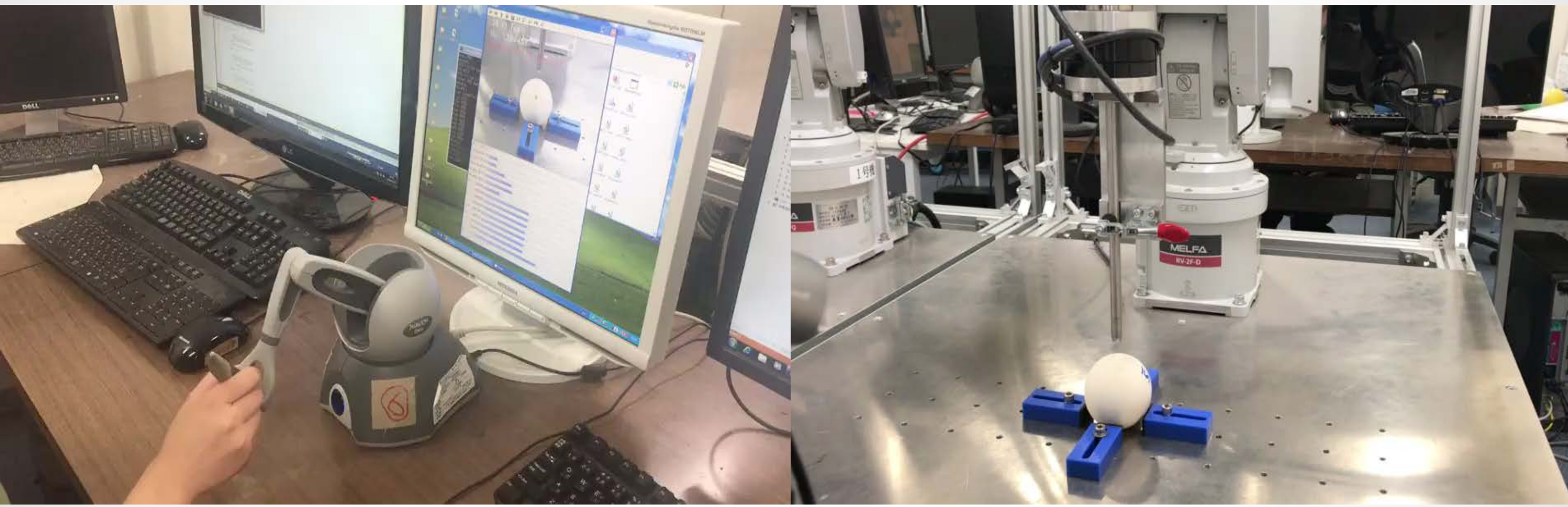
- Three answers:

1. "The first time is closer than the second time."
2. "The second time is closer than the first time."
3. "The first time is almost the same as the second time."

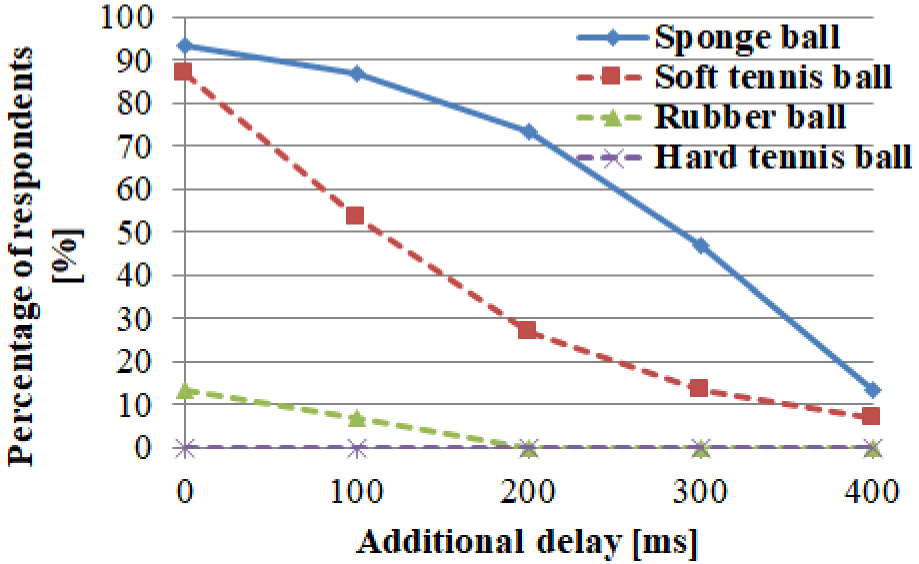
- Random order:

- Combinations of the additional delay and ball
- Two types of control in each combination

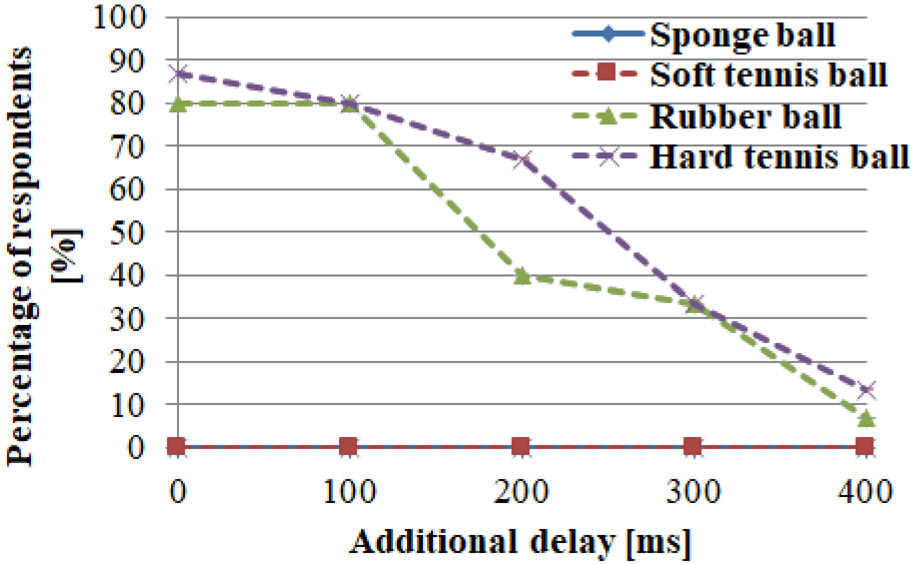
Demo video – Pushing Soft Tennis Ball



Assessment Results (1/3)



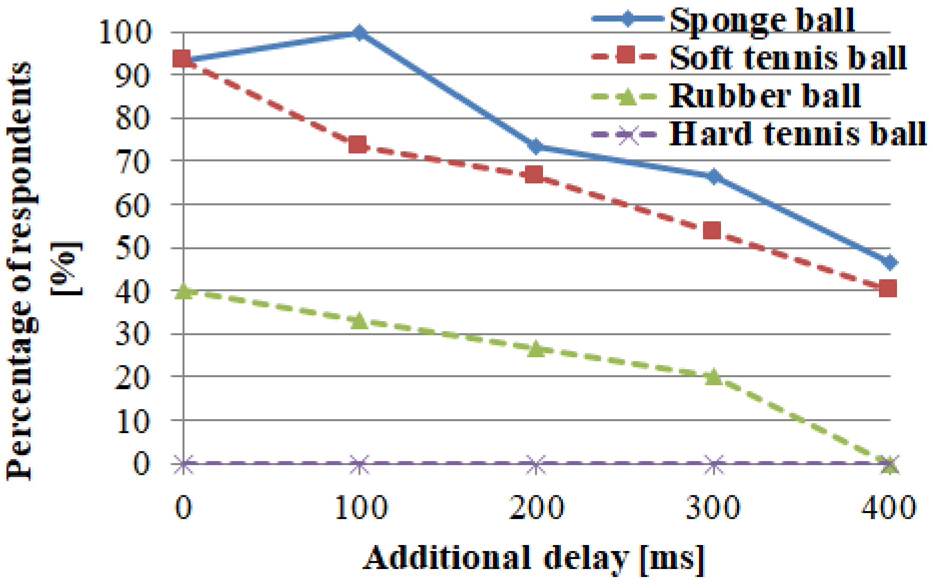
(a) Percentage of respondents who answered that **stabilization control by viscosity** is closer



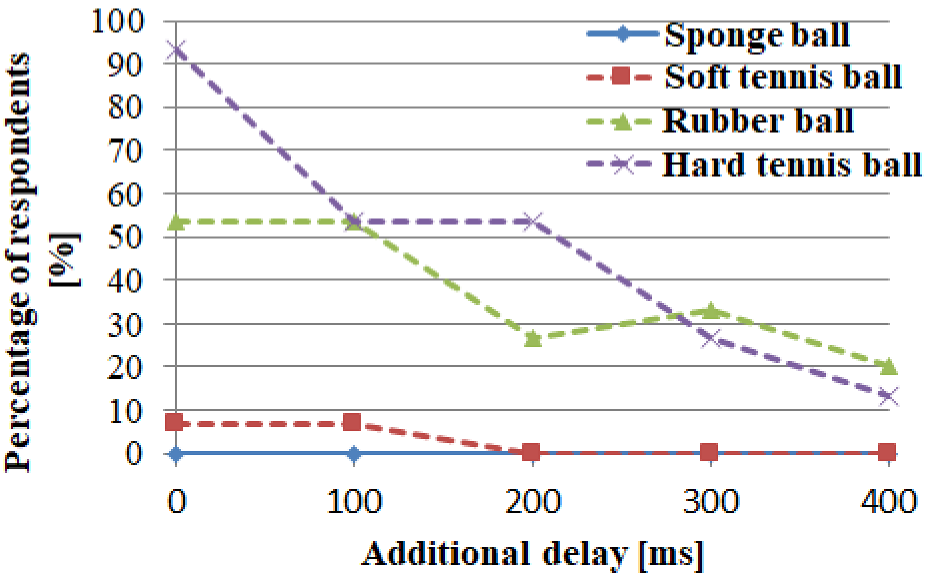
(b) Percentage of respondents who answered that **stabilization control with filters** is closer

Assessment between the stabilization control by viscosity and the stabilization control with filters

Assessment Results (2/3)



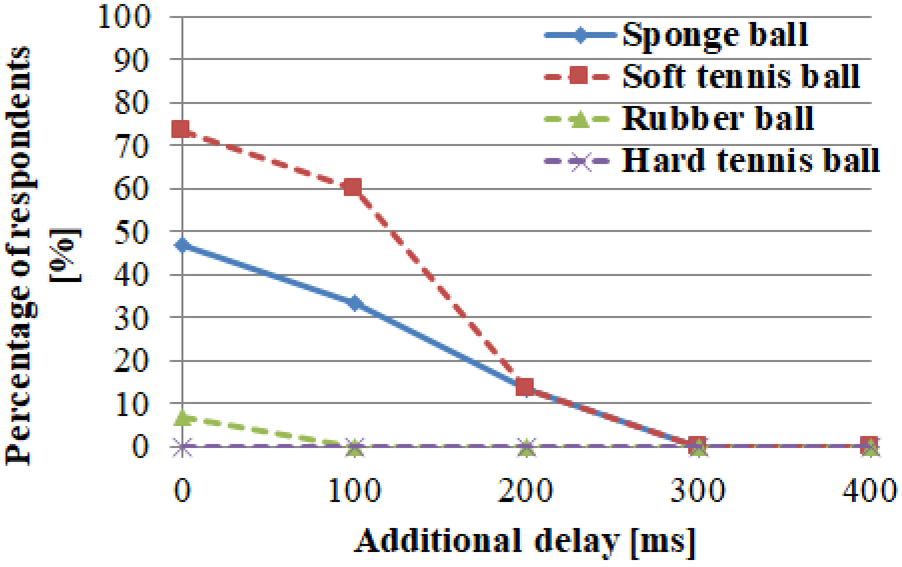
(a) Percentage of respondents who answered that **switching control** is closer



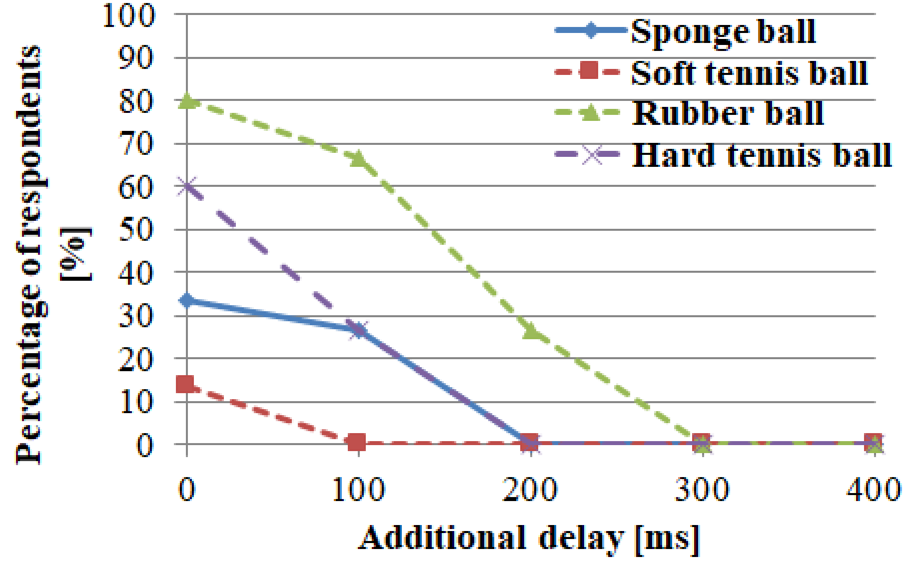
(b) Percentage of respondents who answered that **stabilization control with filters** is closer

Assessment between the switching control and the stabilization control with filters

Assessment Results (3/3)



(a) Percentage of respondents who answered that **stabilization control by viscosity** is closer



(b) Percentage of respondents who answered that **reaction force control upon hitting** is closer

Assessment between the stabilization control by viscosity and the reaction force control upon hitting

*5 R. Arima *et al.*, IEICE, CQ2017-98, Jan. 2018.
*6 Q. Qian *et al.*, IEICE Global Conference, BS-2-14, Mar. 2018.

Summary of Comparison Results

Object	Effective stabilization control			
	Results in this work	Results in *5	Results in *6	Total results
Sponge ball	Viscosity/ Switching	Hitting	Viscosity/ Switching	Viscosity/ Switching
Soft tennis ball	Viscosity/ Switching	Hitting	Viscosity/ Switching	Viscosity/ Switching
Rubber ball	Hitting/ Filter	Filter	Hitting/ Switching	Filter
Hard tennis ball	Hitting/ Filter	Filter	Hitting/ Switching	Filter

Filter: Stabilization control with filters
Viscosity: Stabilization control by viscosity
Hitting: Reaction force control upon hitting
Switching: Switching control

Conclusion

We investigated the effects of the four types of stabilization control on object softness for a remote robot system with haptics by QoE assessment.

We saw that the **switching control** is the most effective among the four types of stabilization control for soft objects, and the **stabilization control with filters** is the most effective for hard objects.

Future Work

- Improvement of the softness quality under the four types of control when the network delay is large

- Combination use of the four types of stabilization control and QoS control (e.g., error control, buffering control, and adaptive reaction force control)